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The Bloch oscillations and mobile electrical domains in 6H-SiC natural superlattice

V. I. Sankin and P. P. Shkrebiy
Ioffe Physico-Technical Institute, St Petersburg, Russia

Introduction

The threshold field of the Bloch oscillation (BO) is:

$$F = 2\pi\hbar/e\tau d. \tag{1}$$

Here τ is the scattering time, d is a period of superlattice (SL). The BO in static regime is expressed as a negative differential conductivity (NDC). It should be noted that for realization the BO regime in crystal the following condition should be performed:

$$eF\ell = E_1, \tag{2}$$

where ℓ — the mean free path, E_1 — the first band width. Therefore to operate with not very large threshold fields semiconductors with relatively narrow band are to construct. In [1] it was shown that in narrow band (miniband) one more effect connected with a zone curvature namely with negative effective mass region is possible. It is difficult to distinguish what one of two effects is observed experimentally because for correct estimations the scattering time at strong fields is necessary.

The 6H-SiC polytype has a natural SL which is created at crystal growth automatically. Therefore such SL should be ideal from structurally quality point of view. The problem is only one of necessary miniband parameters. Our investigation [2] allowed to show a presence the miniband structure in electron band only. The experimental method for investigation I–V characteristics at the fields more than 100 kV/cm was described in [3, 4].

1. I–V characteristics of SiC polytypes in static regime. Experimental observation of the Bloch oscillation

I–V characteristics of tree terminal bipolar experimental structure on the base of 4H-, 6H-, 8H-SiC is shown in Fig. 1. All three curves is characterized by sufficiently extensive NDC region. The threshold fields are different. In accordance with Eq. (2) such situation is possible if E_1 or ℓ different. Indeed the miniband width are different: the most wide for 4H-SiC and the narrowest for 8H-SiC. It correlates with the set of the curves maxima in Fig. 1. We carried out the measurements of drift velocities and the time scattering τ at strong fields were received from Eq. (3). The time scattering for three polytypes were approximately identical: $\tau = 5 \cdot 10^{-13}$ s.

$$V_d = A \cdot \frac{F}{B} \cdot \frac{1}{1 + \left(\frac{F}{B}\right)^2}, \tag{3}$$

where $A = dE_1/2\hbar$, $B = \hbar/ed\tau$, d is the SL period. The experimental values of the threshold fields much nearer to BO Eq. (1).

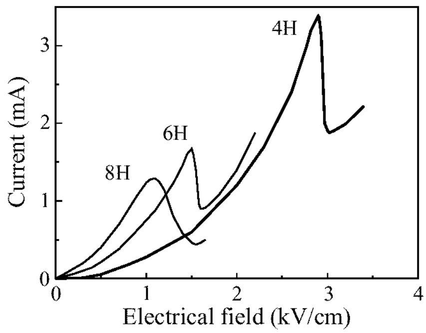

Fig. 1. I–V characteristics of SiC polytypes superlattice.

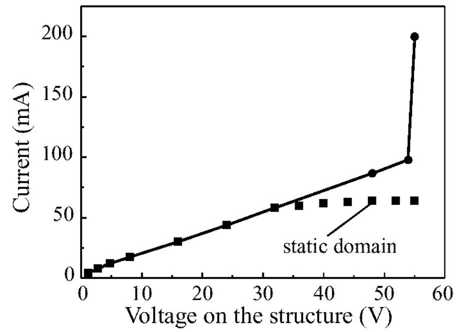

Fig. 2. I–V characteristic of 6H-SiC $n^+–n^-–n^+$ diode structures.

2. The investigation of regime BO in 6H-SiC $n^+–n^-–n^+$ diode structures

The above mentioned three terminal bipolar experimental structure is not available as working sample for UHF measurements because of its long time parameters. To operate in this frequency range the 6H-SiC $n^+–n^-–n^+$ diode structures were developed. The structure consisted of an 3–5 microns base n^--layer doped to $(2–5) \cdot (10^{15}–10^{16})$ cm^{-3}, 0.15 microns upper n^+-layer doped to 10^{20} cm^{-3} and substrate doped to $2 \cdot 10^{18}$ cm^{-3}. In fabrication of structure reactive ion etching was used for creation of mesa isolation 25–40 microns in diameter. Ni sintered by thermal annealing was used as ohmic contacts to n^+-layers. The I–V characteristic of such structure is shown in Fig. 2. It consists of the linear almost ohmic region and the region of the sharp current change. The latter is followed by a light radiation. The spectrum of this radiation is identical to a breakdown radiation in 6H-SiC. Consequently, this region is result from breakdown. But the field in the breakdown point (Fig. 2) do not exceed 150–170 kV/cm. It is less than 15 times of the breakdown field in 6H-SiC (the mean value $F_b = (2–3)$ MV/cm [5]), but it is approximately equal to $F_t = 150$ kV/cm of BO and NDC regime in 6H-SiC (Fig. 1).

As known the NDC state stimulates a generation of the field domain where the field exceeds one in the neighborhood and can achieve the breakdown field. There are some evidences that it is a mobile domain. In a case of static domain the I–V characteristic would be as shown in Fig. 2 by single points. Besides an instability of the domain in initial phase and very low differential resistance (10–20 Ω) of the breakdown region are additional evidences of mobile domain. In case of static domain it would be more than 200 Ω.

3. The investigation of regime BO in 6H-SiC $n^+–n^-–n^+$ triode structures

To obtain more convincing evidences a SiC transistor with static induction have been created for the first time. The channel size was equal to $40 \times 2 \times 3$ μm^3, (Fig. 3).

The idea is the following: if the domain exists in channel the cross field of the gate $p–n$ junction subjecting to the domain will set into its destroying. It do occurred at the field approximately equal to 600 kV/cm resulting in the sharp amplitude reduction of breakdown region on I–V characteristic, Fig. 4 (curve 4).

Therewith the cross field influences on linear region in a usual manner as in field transistor only. The point where spread the cross field is placed so far from cathode that only mobile domain can come up to there. Thus in the channel with 6H-SiC natural superlattice the mobile domain was discovered. It oscillates there with UH frequency and

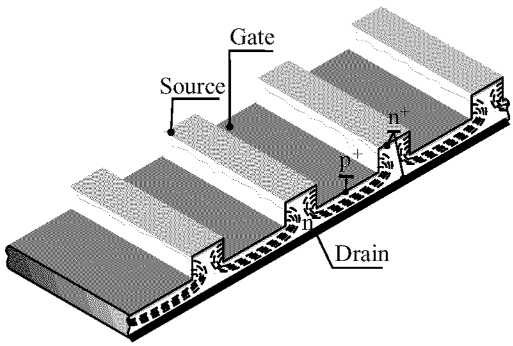

Fig. 3. The common view of ststic induction transistor structure.

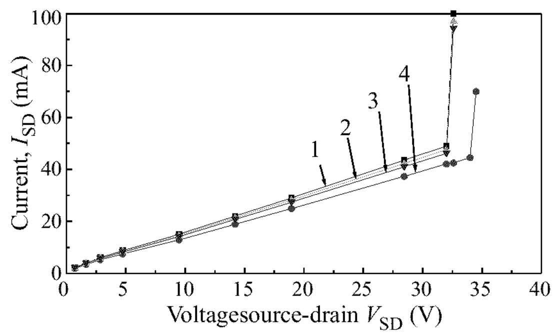

Fig. 4. I–V characteristic of 6H-SiC $n^+–n^-–n^+$ triode structure.

it is the transformed Bloch oscillations which intrinsic frequency is approximately equal to $3 \cdot 10^{12}$ Hz. Unfortunately the sample degrades in this breakdown regime very rapidly. Therefore a direct discovering of UHF oscillations have been as yet impossible. It appears to be because of low quality of the using n-material. It is necessary to repeat the same experiment on 6H-SiC of another technology fabrication.

4. Conclusion

The discovering of NDC and mobile domain due to Bloch oscillations are the more important results in study the strong field transport in SiC superlattice. The presence of unusual mobile domain creating the breakdown avalanche is evidence oscillations possibly with terra Hz frequency.

Acknowledgements

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